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The Influence of Concrete Grinding Residue on Soil Physical Properties and Plant Growth

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The Influence of Concrete Grinding Residue on Soil Physical Properties and Plant Growth

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Abstract

Diamond grinding is a concrete pavement maintenance technique, and concrete grinding residue (CGR) is the byproduct. Concrete grinding residue deposited along roadsides affects soil chemical properties, but impacts of CGR on soil physical properties and plant growth are rarely studied. In this study, a controlled field experiment was performed to determine the influence of CGR on selected soil physical properties (i.e., bulk density [ρ_b], saturated hydraulic conductivity [K_s], and water infiltrability [I_t]) and on plant biomass and plant coverage under four application rates (0, 2.24, 4.48, and 8.96 kg m^{-2}). Field measurements were performed before the CGR applications, and 1, 7, and 12 mo after the CGR applications. No significant CGR effects on soil physical properties were detected. The ρ_b was relatively stable for all of the treatments, whereas some nonsignificant variations (e.g., 10–30% of mean K_s values and mean I_t values among four CGR rates) were found. Plant biomass with a CGR rate of 2.24 kg m^{-2} tended to be 10 to 40% larger than biomass in the control treatment, whereas plant biomass with a CGR rate of 8.96 kg m^{-2} tended to be ~10% smaller than the control treatment. Concrete grinding residue had no significant effects on plant coverage, richness, Simpson's diversity, and evenness. Thus, CGR applications up to 8.96 kg m^{-2} did not significantly affect soil physical properties and plant growth in this controlled field study. This study can serve as a reference for results obtained from roadsides in Minnesota and Iowa that receive CGR applications.

Core Ideas

- Concrete grinding residue (CGR) was evaluated in a controlled field study.
- CGR applications <8.96 kg m^{-2} did not significantly affect soil physical properties.
- CGR applications did not significantly affect plant biomass and community properties.
- The results provided a reference for diamond grinding in Minnesota and Iowa.

Diamond grinding is a commonly used technique for smoothing concrete road surfaces (Neal and Woodstrom, 1976; Rao et al., 1999), which is intended to improve vehicle ride quality, reduce road noise, enhance surface skid resistance, and extend road service life (Defrain, 1989; Mosher, 1985; ACPA, 1997). For diamond grinding, a thin layer of concrete is removed from the road surface using closely spaced diamond saw blades, creating a surface with longitudinal texture at a pre-specified level. Diamond grinding is cost effective and time effective, with relatively little interruption to traffic (McGovern, 1995; Pierce, 1995; Rao et al., 1999).

During diamond grinding, concrete particles from the saw blades are flushed by water. The resulting mixture of water and concrete particles is known as concrete grinding residue (CGR). Concrete grinding residue is a slurry-type amalgam of relatively high pH and alkalinity (Goodwin and Roshek, 1992; Druschel et al., 2012; Kluge et al., 2017). In some states, CGR is collected and transported to specific containment ponds (Caltrans, 2010), or reused as building materials or soil amendments (Goodwin and Roshek, 1992; Kluge et al., 2017). However, states in the US Midwest region allow direct depositions of CGR along roadsides, which may lead to potential environmental risks to roadside soils, to plants along road shoulders, and to water in roadside ditches (Druschel et al., 2012; Wingeyer et al., 2018).

Concrete grinding residue has been investigated at a few locations, with a focus on its chemical properties. The pH of CGR has been reported to range from 9.0 to 12.5 at multiple sampling locations across the United States (Goodwin and Roshek, 1992; Yonge and Shanmugam, 2005; Hanson et al., 2010; DeSutter et al., 2011a; Wingeyer et al., 2018). Wingeyer et al. (2018) reported that the effective calcium carbonate equivalent values of CGR were up to 28.1% for samples in Nebraska, with K, Na, Mg, and Ca found to be the most abundant cations (DeSutter et al., 2011a). In the leachate of CGR samples from California, concentrations of toxic elements such as As, Ba, Cd, Cr, Cu, Hg, Pb, Se, and Zn in CGR were either below the limits based on the 40 CER 261 standard or below detection levels, or even smaller than the background values of roadside soils (Caltrans,

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Abbreviations: CGR, concrete grinding residue; EC, electrical conductivity; RCBD, randomized complete block design.

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1997; DeSutter et al., 2011a); although concentrations of Al, Fe, SO_4, and NO_3 or NO_2 in CGR exceeded the California drinking water standard (Caltrans, 1997). However, for CGR samples from Florida, Kluge et al. (2017) reported that concentrations of Cr, Mo, and Sr exceeded the Florida groundwater cleanup target levels, through EPA 1316 tests. Organic toxic compounds, such as benzene, toluene, ethylbenzene, and xylene, had concentrations either below detection levels or below the California drinking water standard (DeSutter et al., 2011a; Kluge et al., 2017). Caltrans (1997) reported that concentrations of oil, grease, and total petroleum hydrocarbon in their samples were just above the detection levels and did not reach hazardous levels. DeSutter et al. (2011a) reported that none of 16 selected polynuclear aromatic hydrocarbons were detected in CGR based on USEPA Method 8270C. Thus, CGR displayed limited hazardous characteristics in its inorganic and organic constituents, which were similar to those expected for the concrete exposed to traffic and construction activities (Kluge et al., 2017).

Investigations showed that soil chemical responses to CGR were consistent. Although CGR deposited on soil led to immediate increases in pH values (Yonge and Shanmugam, 2005; Wingeyer et al., 2018), the initially elevated pH values decreased with respect to time (Wingeyer et al., 2018). Soil electrical conductivity (EC) and concentrations of K, Na, Mg, and Ca were initially affected by CGR applications, but such effects were diminished after a 1-yr period (Wingeyer et al., 2018). Concentrations of heavy metals such as Pb, Cu, Zn, and Cd in CGR-affected areas were not significantly different from soil background values (Yonge and Shanmugam, 2005). Concrete grinding residue could also affect soil physical properties, especially the hydraulic properties. However, such effects have not been fully studied, and reported results, such as the infiltration results by DeSutter et al. (2011a), were not directly from field measurements. In addition, the physical effects of CGR might manifest over a relatively long period, possibly due to the slow redistribution of CGR particles within soil profiles. Thus, there is a need for further investigation of the CGR impacts on soil physical properties.

Concrete grinding residue deposits can also affect roadside plant growth. Wingeyer et al. (2018) reported no significant CGR effects on roadside plant biomass and botanical production, whereas DeSutter et al. (2011b) used a greenhouse experiment to analyze the influence of various CGR deposit rates on early stage plant biomass of smooth brome (*Bromus inermis* Leyss.) and reported that 8% CGR, based on the soil dry mass, promoted early-stage growth. Because plant community properties, such as plant species and coverage, have not been thoroughly investigated, and the data for plant biomass responses to CGR are limited and inconsistent, there exists a need to further study the impacts of CGR on plant growth.

Thus, the objectives of this study are to perform a controlled CGR field experiment to determine the impacts of CGR on (i) selected soil physical properties (soil bulk density [ρ_b], saturated hydraulic conductivity [K_s], and soil water infiltrability [I_t]) and (ii) aboveground plant biomass and plant coverage for individual species. Both field investigations and laboratory measurements are performed in this study, and the results can serve as a reference study for comparison with results obtained from other less controlled CGR studies on highway roadside soils and plants in Iowa and Minnesota.

Materials and Methods

The CGR used in this study was obtained from a diamond grinding project located at 6078 to 6216 McAndrews Road in Apple Valley, MN. Approximately 500 L of CGR slurry was collected and transported to Iowa for use in a controlled field experiment. The gravimetric water content of the CGR slurry was 0.54 g g^{-1}. The controlled field experiment was performed at the Kelly Farm research site, at 1119 to 1149 XL Avenue, Boone County, Iowa (42°02′ N, 93°42′ W), on Clarion loam soil (fine-loamy, mixed, superactive, mesic Typic Hapludolls). The particle size distributions of both CGR and Clarion loam soil are shown in Table 1.

A reconstructed prairie, including cool-season grasses, warm-season grasses, leguminous forbs, and nonleguminous forbs, existed at the research site since 2013. The research site was divided into 16 square plots, each with an area of 4 m^2. The buffer space between adjacent plots was 2 m, with 4-m margins at the outer edges of the research site. The prairie was mowed to a height of 30 cm before CGR was applied, which assisted the uniform application of CGR to the soil surface. In October 2016, CGR slurry was fully mixed in a 170-L water tank for several hours, and the water content was measured. Then CGR slurry was spread homogeneously on the surface of each plot at one of four designed rates based on CGR dry mass (i.e., 0, 2.24, 4.48, and 8.96 kg m^{-2}). The application rates were similar to the rates reported in Wingeyer et al. (2018), and replications at each rate were performed. A randomized complete block design (RCBD) was used. Field measurements of ρ_b, K_s, I_t, and plant biomass were performed four times: October 2016 (before the CGR application), November 2016 (1 mo after CGR application), May 2017 (7 mo after CGR application), and October 2017 (12 mo after CGR application). Measurements of plant species coverage (i.e., plant investigations) were performed before the CGR application (in 2016), and after the CGR application (in 2017 and 2018).

The background soil pH and EC were about 6.2 and 0.5 dS m^{-1}, whereas after CGR applications, the surface soil pH increased by 1 to 1.5 units, and the surface soil EC values were up to between 1 and 2.5 dS m^{-1}, depending on the CGR rates. The detailed variations in alkalinity, metal concentrations, cation exchange capacity, exchangeable sodium, and base saturation under CGR impacts were reported by Yang et al. (2019).

For the ρ_b and K_s measurements, 7.62-cm-diam. by 7.62-cm-height aluminum cylinders were used to obtain three undisturbed soil cores from the soil surface layer in each field plot. The upper and lower surfaces of each sample were trimmed and marked. The soil cores were saturated in a vacuum chamber with a 5 mmol L^{-1} $CaCl_2$ solution, then a constant head ponded infiltration experiment was used to determine K_s. After computing the K_s, the soil core samples were oven dried at 105°C until constant mass to calculate ρ_b.

A Cornell sprinkle infiltrometer was used to measure field water infiltrability (van Es, 1993; Ogden et al., 1997). A 24.1-cm-diam. aluminum infiltration ring was inserted into the surface soil. The plants and residues in the infiltration ring were maintained, but the plant height was below the upper edge of the infiltration ring. A simulated rainfall rate from the Cornell sprinkle infiltrometer of 0.015 cm s^{-1} was selected based on preliminary tests, to encourage surface runoff to determine steady infiltration rates. The steady infiltration rates per unit area were taken as the I_t values.

Table 1. Particle size distribution of Clarion loam soil and concrete grinding residue (CGR).

Particle size	Soil	CGR
	%	
Sand (2–0.05 mm)	50	39
Coarse Silt (0.05–0.02 mm)	17	15
Fine Silt (0.02–0.002 mm)	14	38
Clay (<0.002 mm)	19	8

A 50-cm by 100-cm quadrat was selected in each plot for plant species investigation. The covering percentage for each species was estimated using the scales of 0 to 1%, 1 to 5%, 5 to 25%, 25 to 50%, 50 to 75%, 75 to 95%, or 95 to 100%, and the midpoint of each scale was used to represent the covering percentages of individual species in each plot (Bonham, 1989). Covering percentage, species richness (R), Simpson's diversity (D), and Simpson's evenness (E) were used to evaluate the impacts of CGR on plant community. The covering percentage was summed with respect to functional groups (cool-season grasses, warm-season grasses, leguminous forbs, and nonleguminous forbs) in each plot, whereas the number of species in each functional group was taken as R. The D and E were computed for each plot instead of each functional group. The reciprocal of the squared sum of the ratio of covering percentage for each species, which was the covering percentage of individual species in each plot divided by the total covering percentage for that plot, was taken as D, and E was equal to D divided by the total number of species in each plot (Morris et al., 2014; Kordbacheh et al., 2018). A 20-cm by 50-cm quadrat close to the plant investigation quadrat was selected in each plot to determine the aboveground plant biomass. The aboveground part of the green vegetation was clipped at a height <5 mm above the soil surface and stored in paper bags. Dead plant residue from previous years was not included. The biomass samples were oven dried at 65°C for 4 d (García et al., 1993), and the oven-dried biomass values were measured.

Analysis of variance models were used to process the measured data and determine whether the CGR applications significantly influenced soils and plants for each measurement time. In the RCBD, the following linear model was applied:

$$y = T_r + B_l + \varepsilon \qquad [1]$$

where T_r represents the effects induced by CGR, B_l represents the block effect, ε represents the model error, and y represents the responses. In background measurements before the CGR applications, there were no active CGR effects, so T_r was omitted. Because K_s and I_t followed lognormal distributions (Smith and Hebbert, 1979; Jabro, 1992; Kosugi, 1996), a logarithmic transformation was applied to the K_s and I_t data before the ANOVA analyses. For plant community properties, probability distributions of the covering percentage, R, D, and E were tested based on the Cullen and Frey graph (Delignette-Muller and Dutang, 2015) prior to the analysis, and ANOVA with appropriate distributions was applied via general linear model, implemented in R statistical analysis packages. Statistical analyses were restricted to each measurement time, and variations in time domain were not included, because such differences in the measurements could be due to seasonality, which did not directly represent the effects caused by CGR applications.

Results and Discussion

Results of Bulk Density, Saturated Hydraulic Conductivity, Infiltrability, and Aboveground Biomass

Table 2 presents the mean values of ρ_b, K_s, I_t, and aboveground biomass for the four CGR rates in the controlled field experiment. The CGR and block effects were represented as p values. Given these results, the background values in the research plots did not differ significantly, indicating the homogeneity of soil properties, and the uniformity of plant biomass after the initial mowing at the study site. The measured results after CGR applications indicated that CGR had no statistically significant influences on the soil physical properties or the plant biomass during the 12-mo experimental period.

Figure 1 presents a comparison of ρ_b, K_s, I_t, and aboveground biomass values among the four CGR treatments. An example to interpret the box plot is shown in Fig. 1a. For K_s and I_t, the box plots are presented in log scales. The box plots serve as a simple verification of the data normality, since the median and mean values are similar, and the box edges are nearly symmetrical about the median values in general. The box plots also provide a visualization of the ANOVA analyses, where for each measurement time, the mean values for one CGR rate are within the 95% confidence intervals of the mean values for the other CGR rates.

The ρ_b values, shown in Fig. 1a, are relatively stable during the experiment period. The coefficients of variation for ρ_b (i.e., the standard deviation divided by the mean ρ_b) among the CGR rates were as low as 0.05. For each CGR rate, the ranges of the mean ρ_b values (i.e., the difference between the maximum values and the minimum values of mean ρ_b for each CGR rate) during the 12-mo period did not exceed 0.08 g cm^{-3}, and it was usually <0.05 g cm^{-3}.

The comparison of K_s values among the four CGR rates is shown in log scale in Fig. 1b. For the three measurement times after CGR application, the K_s values with CGR, on average, tended to be slightly smaller than the K_s values from the control treatment. In the 12-mo measurements, the mean K_s values for the 4.48 and 8.96 kg m^{-2} CGR rates tended to be ~30% smaller than the mean K_s for the 0 kg m^{-2} CGR rate, whereas the mean K_s value for the 2.24 kg m^{-2} CGR rate was only slightly smaller than the mean K_s for the 0 kg m^{-2} CGR rate. Such trends were not consistent with results reported by DeSutter et al. (2011a), because in this experiment, measurements were made on undisturbed site samples obtained directly from the controlled field site, whereas DeSutter et al. (2011a) used a disturbed soil sample.

A comparison of I_t values in log scales among the four CGR rates is shown in Fig. 1c. For the 1-mo measurement, mean I_t values of CGR treatments tended to be larger than the mean value in the control treatment, whereas for the 7-mo measurements, the mean I_t values of CGR treatments tended to be smaller than the mean value for the control treatment. Especially for the 8.96 kg m^{-2} CGR treatment, the mean I_t value was ~30% smaller than the corresponding control treatment results. However, for the 12-mo measurements, the mean I_t values of the CGR treatments and the control treatment tended to be more similar than the differences that occurred in the 7-mo measurements. Thus, the differences between mean I_t after CGR applications and the mean I_t in the control treatment were not statistically significant, and the differences in mean values did not follow specific trends.

Table 2. The ANOVA results of the soil physical properties of bulk density (ρ_b), saturated hydraulic conductivity (K_s) and infiltrability (I_t) and plant biomass in the controlled field experiment.

Property	Measurement	Date	CGR application rate				p (CGR)†	p (BLK)‡
			0 kg m^{-2}	2.24 kg m^{-2}	4.48 kg m^{-2}	8.96 kg m^{-2}		
ρ_b	Background	Oct. 2016	1.24	1.21	1.25	1.26	–	0.66
	1 mo	Nov. 2016	1.25	1.33	1.25	1.19	0.11	0.85
	7 mo	May 2017	1.33	1.32	1.31	1.27	0.41	0.31
	12 mo	Oct. 2017	1.26	1.27	1.26	1.21	0.09	0.35
K_s	Background	Oct. 2016	0.051	0.022	0.038	0.032	–	0.19
	1 mo	Nov. 2016	0.061	0.058	0.038	0.037	0.09	0.28
	7 mo	May 2017	0.036	0.027	0.034	0.029	0.60	0.72
	12 mo	Oct. 2017	0.031	0.030	0.020	0.019	0.20	0.22
I_t	Background	Oct. 2016	0.0081	0.0069	0.007	0.0074	–	0.80
	1 mo	Nov. 2016	0.0056	0.007	0.0069	0.0072	0.33	0.37
	7 mo	May 2017	0.0105	0.0087	0.0088	0.0075	0.11	0.27
	12 mo	Oct. 2017	0.0098	0.0093	0.0093	0.0096	0.95	0.45
Biomass	Background	Oct. 2016	0.61	0.68	0.70	0.60	–	0.48
	1 mo	Nov. 2016	0.35	0.47	0.45	0.39	0.55	0.64
	7 mo	May 2017	0.47	0.54	0.38	0.42	0.48	0.18
	12 mo	Oct. 2017	0.73	0.10	0.85	0.65	0.36	0.06

† p (CGR), p values for concrete grinding residue (CGR) main effect.

‡ p (BLK), p value for block effect.

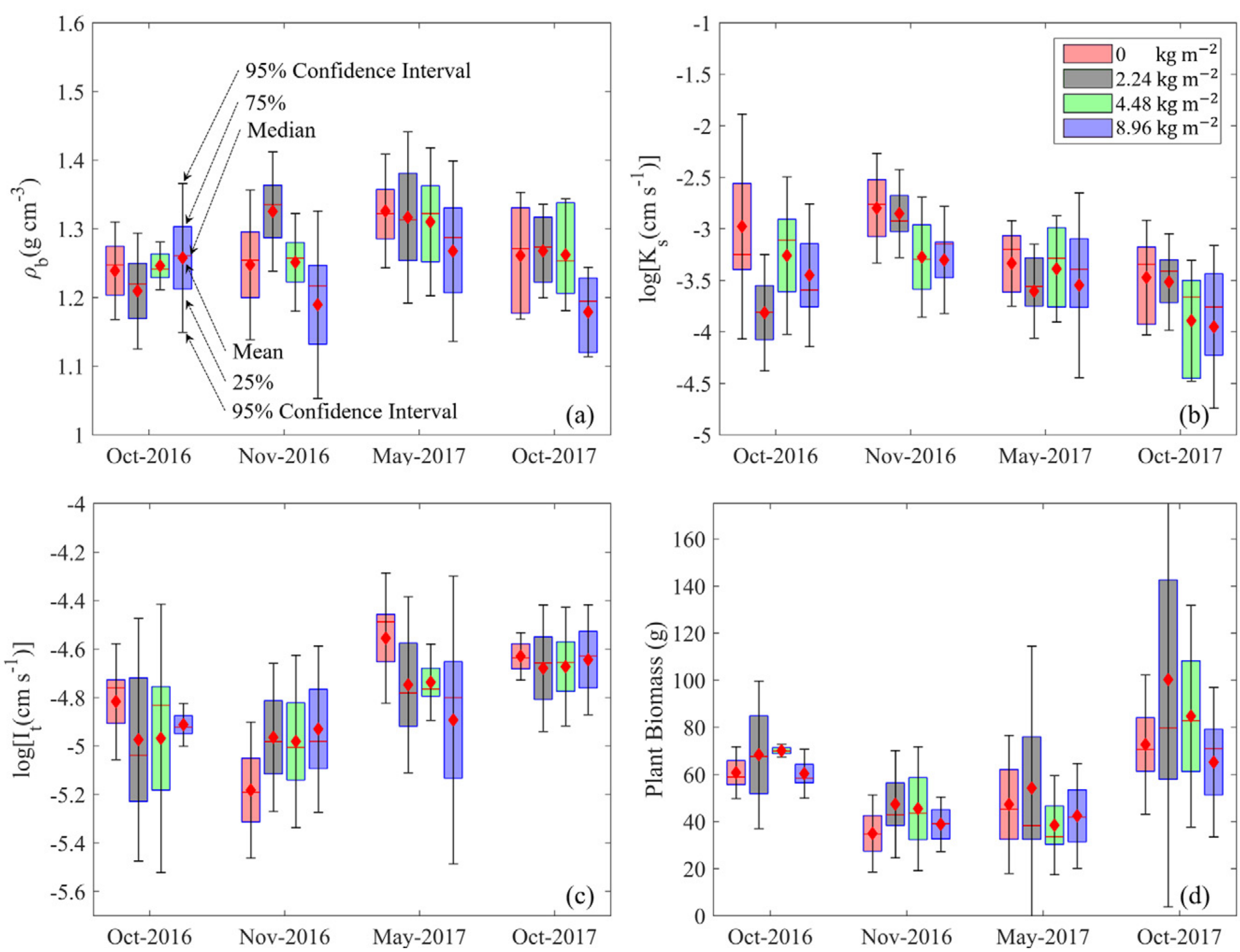

Fig. 1. The measured bulk density (ρ_b), saturated hydraulic conductivity (K_s), infiltrability (I_t), and aboveground biomass values, with 25 and 75% percentiles, 95% confidence intervals (error bars and whiskers), with mean values and median values signified.

Both I_t and K_s values reflect soil hydraulic properties. However, the trends in mean I_t and mean K_s values differed. One possible reason is that I_t values were directly obtained in the field, where plant residue and soil surface topography could affect the results, whereas K_s values were determined in the laboratory on saturated soil core samples, where the soil surface was flat and plant roots were trimmed off. Moreover, the I_t values represented larger diameter measurements than did K_s. The Clarion loam soil series included in this study is extensively distributed in north-central Iowa and south-central Minnesota, and thus the soil physical results obtained from this controlled field study can reinforce the understanding of CGR effects on roadside soil in these two states.

Figure 1d presents plant biomass values. Due to seasonal effects, biomass values decreased from October 2016 to November 2016 and increased from May 2017 to October 2017. Focus was placed on results from the two field measurements in 2017, because they represented plant growth during a new growing season after the CGR application. Consistent with the results reported by Wingeyer et al. (2018), the differences in biomass among the CGR application rates were not statistically significant, probably because the plant tissue has a buffering capacity for leveraging the instantaneous influences of CGR on soil. However, there were some plant growth trends consistent to the greenhouse study results reported by DeSutter et al. (2011b). For example, the plant biomass for the 2.24 kg m^{-2} CGR rate had, on average, the largest values compared with the other CGR rates, with biomass values 15 and 38% larger than the corresponding values from the control treatment. However, the biomass values for the larger CGR rates tended to be relatively small. The smallest biomass in May 2017 occurred in the 4.48 kg m^{-2} CGR rate and was 19% smaller than the control treatment value. In October 2017, the smallest biomass value was obtained with

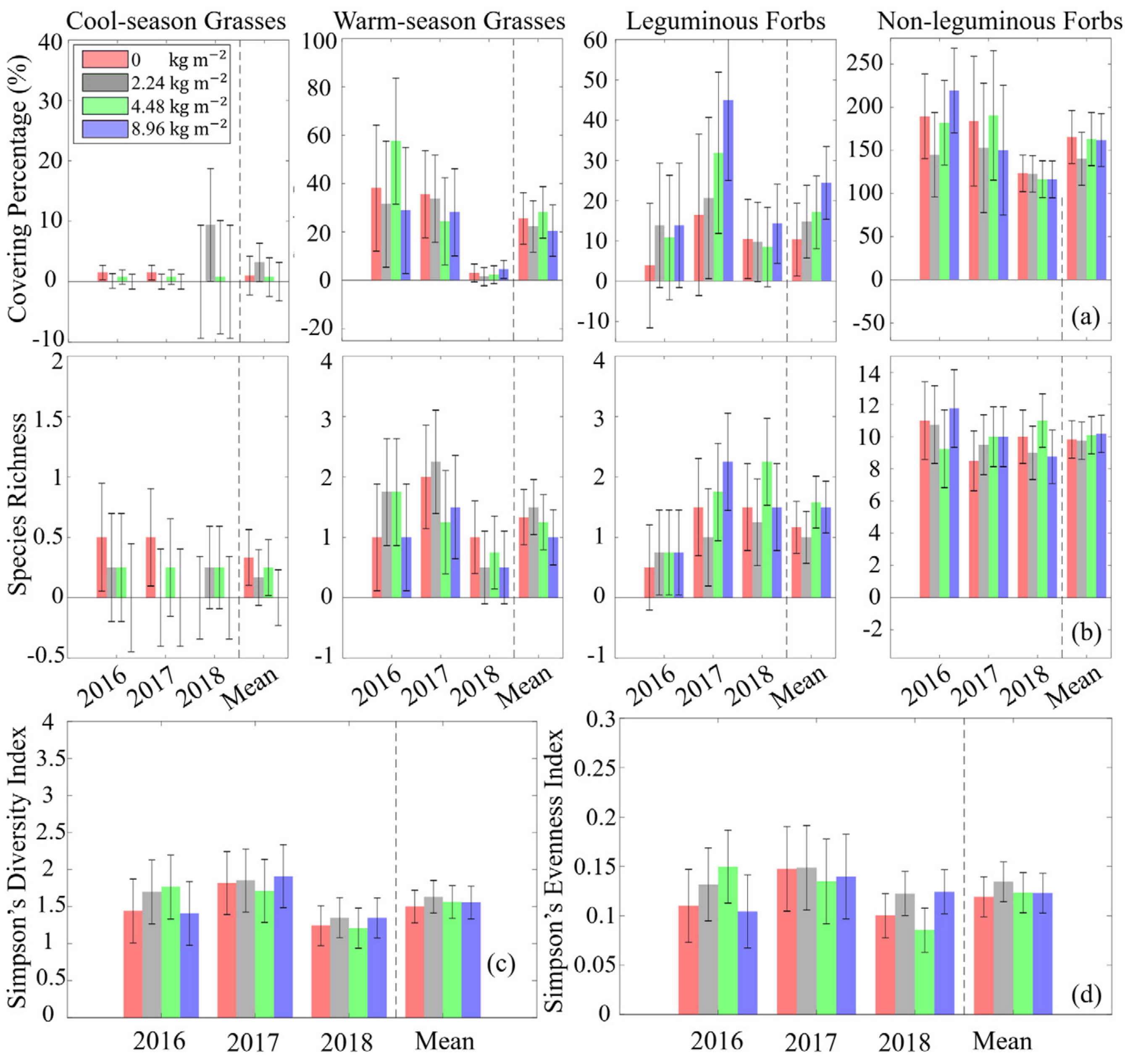

Fig. 2. The (a) covering percentages for each functional group, (b) species richness for each functional group, and (c) Simpson's diversity indices and (d) Simpson's evenness indices for the entire plant community within each treatment and year of the experiment. The error bars represent ±1 SD, and the ANOVA results of the comparison of treatments within each year are presented for Simpson's diversity indices and Simpson's evenness indices.

the 8.96 kg m^{-2} CGR rate and was 10% smaller than the control treatment value. The results indicated that a small amount of CGR tended to promote plant growth, possibly because CGR could supply inorganic nutrients to the plant or regulate soil pH or EC values. However, a relatively large amount of CGR tended to inhibit plant growth.

Results of Plant Coverage

The covering percentage and R values are shown in Fig. 2a and 2b for each functional group, whereas the results of D and E are shown in Fig. 2c and 2d for the entire plant community. The error bars indicate ± 1 SD. The reason for separating the functional groups in Fig. 2a and 2b was that some of the functional groups (e.g., cool-season grasses and warm-season grasses) had relatively small covering percentages and R values. If the four functional groups in each plot were analyzed together, their results could be masked by functional groups with relatively large covering percentages and R values (e.g., nonleguminous forbs). However, relatively low covering percentages and R values could reduce the representability and numerical stability in the computation of D and E. Thus, D and E were calculated for each plot. An ANOVA was performed for all of the four plant community properties, and the results are shown in Table 3. For the background measurements in 2016, only the block effects were included. For the measurements in 2017 and 2018, both CGR treatment and block factors were included. For the covering percentage and R, the spatial distribution of each functional group was homogeneous, with p values for the block factor >0.3 in general, and the CGR effects on covering percentage and R of each functional group were not statistically significant. Concrete grinding residue did not significantly affect the D value of each plot among the four application rates either. In contrast, for the measurements in 2018, a significant difference was observed in E results, and the smallest values occurred in the 4.48 kg m^{-2} CGR rate, because of a dramatic decrease of *Taraxacum officinale* F.H. Wigg. However, the dramatic decreasing pattern of *Taraxacum officinale* was not found at the highest CGR rate (i.e., the 8.96 kg m^{-2} CGR treatments). Moreover, based on the differences of E among CGR rates shown in Fig. 2d, the CGR effects on E were not consistent (i.e., not constantly increasing or decreasing with respect to CGR rates). Thus, the relatively small value of E in the 4.48 kg m^{-2} CGR treatments was likely a random event due to a covering percentage change of a single plant species.

Based on the comparison of the plant coverage for each species, it was also possible to identify some species that were not influenced by CGR, such as *Solidago canadensis* L. and *Helianthus grosseserratus* M. Martens. Some species had tolerances to low CGR rates (i.e., 2.24 kg m^{-2}), such as *Zizia aurea* (L.) W.D.J. Koch and *Taraxacum officinale*. Some species declined in response to CGR, such as *Vitis riparia* Michx. In general, the CGR applications did not lead to significant effects on plant community properties. The plant species selected in this

Table 3. The ANOVA results of the plant community properties of cool-seasoned grasses (CS), warm-seasoned grasses (WS), leguminous forbs (LF), and nonleguminous forbs (NL) in this controlled field experiment

Property	Application rate	2016				2017				2018			
		CS	WS	LF	NL	CS	WS	LF	NL	CS	WS	LF	NL
	kg m^{-2}												
Covering percentage (%)	0	1.5	38.1	3.9	189.5	1.5	35.6	16.5	183.9	0.0	3.0	10.5	123.2
	2.24	0.1	31.5	13.9	144.9	0.0	33.8	20.6	152.9	9.4	1.5	9.8	122.8
	4.48	0.8	57.6	10.9	182.0	0.8	24.4	31.9	190.6	0.8	2.2	8.5	116.6
	8.96	0.0	28.9	13.9	219.4	0.0	28.1	45.0	150.2	0.0	4.5	14.2	116.4
	p (CGR)†	–	–	–	–	0.10	0.38	0.21	0.31	0.37	0.60	0.58	0.92
	p (BLK)‡	0.82	0.72	0.54	0.85	0.88	0.72	0.83	0.35	0.54	0.19	0.87	0.49
Richness	0	0.5	1.0	0.5	11.0	0.5	2.0	1.5	8.5	0.0	1.0	1.5	10.0
	2.24	0.2	1.8	0.8	10.8	0.0	2.2	1.0	9.5	0.2	0.5	1.2	9.0
	4.48	0.2	1.8	0.8	9.2	0.2	1.2	1.8	10.0	0.2	1.8	2.2	11.0
	8.96	0.0	1.0	0.8	11.8	0.0	1.5	2.2	10.0	0.0	0.5	1.5	8.8
	p (CGR)	–	–	–	–	0.21	0.18	0.13	0.50	0.45	0.47	0.10	0.16
	p (BLK)	0.43	0.36	0.52	0.64	0.89	0.34	0.54	0.37	0.43	0.67	0.35	0.44
Simpson's diversity index	0	1.44				1.82				1.24			
	2.24	1.70				1.85				1.35			
	4.48	1.77				1.71				1.21			
	8.96	1.41				1.91				1.35			
	p (CGR)	–				0.79				0.74			
	p (BLK)	0.11				0.47				0.80			
Simpson's evenness index	0	0.11				0.15				0.10			
	2.24	0.13				0.15				0.12			
	4.48	0.14				0.13				0.09			
	8.96	0.11				0.14				0.12			
	p (CGR)	–				0.37				0.0013**			
	p (BLK)	0.93				0.82				0.82			

** Significant at the 0.01 probability level.

† p (CGR), p values for concrete grinding residue (CGR) main effect.

‡ p (BLK), p value for block effect.

study follow the roadside plant list in Iowa, based on information provided in https://secure.iowadot.gov/lrtf/NativePlantPublic.aspx and in Quarles (2003). Thus, the plant results obtained in this study can also be generalized to typical roadside conditions in Iowa and Minnesota.

Summary

A controlled field experiment was performed to investigate the influence of CGR slurry on soil physical properties and plant growth. Four CGR rates (0, 2.24, 4.48, and 8.96 kg m^{-2}) were applied to 16 field plots, following a RCBD. Soil bulk density (ρ_b), saturated hydraulic conductivity (K_s), soil water infiltrability (I_t), aboveground plant biomass and plant coverage were measured. The ANOVA tests indicated that the effects of CGR on soil physical properties were not statistically significant. Soil bulk density was a relatively stable property with respect to CGR applications. The I_t values varied among the four measurements, but no CGR effect was shown. Although not statistically significant, mean K_s values tended to decrease as CGR rates increased. Small amounts of CGR tended to promote plant biomass, and large amounts of CGR tended to impede plant biomass; however, such influences were not statistically significant. In general, CGR did not lead to significant influences on plant coverage based on the comparison of covering percentage, species richness (R), Simpson's diversity (D), and Simpson's evenness (E). In conclusion, direct deposits of CGR up to 8.96 kg m^{-2} did not lead to statistically significant effects on soil physical properties and plant growth for a 12-mo controlled field study. The results obtained in this study can serve as a reference for comparison with other less controlled roadside experiments and help develop CGR deposition guidelines for CGR application along Iowa and Minnesota roadsides.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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